

operations of harvesting the wood crop. Practical methods are now known by which forest lands can be used for timber production and yet contribute substantially to waterflow retardation and erosion prevention. It is possible to improve the hydrologic functions of many of the existing tracts of forest and woodland and to reestablish a protective forest growth on many acres of deteriorated cultivated crop and pasture land no longer usable for that purpose.

TO ACCOMPLISH EFFECTIVE land treatment for flood prevention is not simply a question of money—limitless funds would not produce the results without the complete and willing cooperation of the landowner and the operator. The cooperation can be achieved once the land user realizes that erosion and water control on the land will also mean better crops, easier management for him, and a reduction in floods and sediment downstream.

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Frozen Soil and Spring and Winter Floods

Herbert C. Storey

Along with heavy rains and rapidly melting snow as the causes of floods in winter and in early spring, one should consider frozen soil.

Consider first, though, some mistaken beliefs about the occurrence, characteristics, and the effects of frozen soil. Many persons think that if sub-freezing temperatures persist for some time, the soil will freeze uniformly over large areas or that once soil is frozen it becomes impermeable and stays frozen until the spring thaw. Some element of truth resides in those ideas: It is true that if temperatures remain below freezing for a time, some soils start to freeze. It is also true that some frozen soils prevent infiltration. It is also true that some soils have remained frozen throughout the winter.

Soil freezing is an important hydrologic factor in the part of the United States where low winter temperatures prevail and the snow cover is light. Its southern boundary is a line extending from the vicinity of New York City southwesterly across New Jersey and Pennsylvania, and west across southern Ohio, Indiana, and Illinois, through the upper part of Missouri and Kansas, then southwest to the Rocky Mountains in the lower part of Colorado, north along the eastern edge of the Rockies into southern Wyoming, westerly to the northeast part of Utah and the southeast part of Idaho, then east and north again along the east front of the Rockies through Wyoming and Montana. Another zone, separated from the main area by the northern Rockies, includes the eastern one-fourth of Washington and a small part of northeastern Oregon.

Soil freezing does occur south of that line, but it is largely intermittent (freezing at night, thawing during the

day) or only infrequently does it have much hydrologic importance.

Four characteristics of frozen soil bear on its part in floods. Its structure determines how fast rain or melting snow can enter the soil. The depth of penetration of soil frost determines how fast the frost leaves the soil during thaws. The persistence of soil frost determines whether soil will remain frozen through periods of snowmelt. The extent of frozen soil indicates how much of a watershed might be affected.

We use four terms to describe the structure of frozen soil: Concrete, honeycomb, stalactite, and granular.

Concrete frost structure has many thin ice lenses and small crystals and is extremely dense. It usually occurs in soils previously frozen and thawed or in soils settled by a heavy rain. It is most prevalent in bare soils or in soils with a sparse cover of vegetation. It is associated usually with freezing to a great depth.

The honeycomb type has a loose, porous structure. It is easily broken into pieces. It is commonly found when freezing is shallow—usually in early winter—and when soils of high organic content are highly aggregated.

Stalactite frost structure has many small icicles that connect the heaved surface to the soil below. The icicles consist of tiny columns often partly fused into sheets or loosely bound blocks. Stalactite frost often is formed during a refreeze of a partially thawed honeycomb structure.

Granular frost consists of a loose, porous arrangement of small granules or crystals of ice scattered through the soil. It usually occurs in shallow freezing in soils high in organic material. Granular frost often precedes the formation of honeycomb frost. It is quite easily penetrated by a spade or soil auger and may be broken into pieces.

Frost penetration expresses the depth of soil freezing. Deep penetration is associated with dense, impermeable frost and with long persistence, and thus is important as an indicator of structure, persistence, and extent.

Persistence is an important characteristic, because if an impermeable type of frost structure continues through the period of snowmelt, runoff will be high. Even if the frost has melted part-way down from the surface, movement of water down through the soil will be prevented or retarded until the frost goes.

The extent of impermeable frost is an important index of how a watershed will respond to a storm or period of snowmelt. A watershed whose soil is nearly 100 percent concretely frozen yields a much higher runoff in a storm than one only 25 percent of whose soil is frozen, even though the penetration of frost in the latter might be greater than in the first.

FROST STRUCTURE has much to do with the winter infiltration capacity of soils. Concretely frozen soils are relatively impermeable, but the other frost structures seem to have little effect on water movement into and through the soil. As little as 1 inch of concrete frost prevents infiltration of rain or melting snow.

The effect of soil freezing in retarding percolation is greater for heavy-textured soils than for light-textured soils. When concrete frost is present during storm periods, surface runoff—often as much as 100 percent of the precipitation—results. Measurements made during a flood period in March 1936 in southern New York showed that 100 percent of the rainfall ran off concretely frozen bare fields and that little or no runoff occurred on nearby unfrozen, forest-covered soils.

Measurements made in 1941 near Cohocton, N. Y., showed that the runoff from three small cultivated watersheds was directly related to the areal extent of the frost in the soil. In one drainage, where 25 percent of the area contained frost during the melt period, the runoff amounted to 12 percent of the total rainfall and snowmelt water. Where the frost covered 63 percent of the area, the runoff amounted to 41 percent of the available water.

Where frost was found on 93 percent of the area, runoff was 53 percent of the available water. Thus the presence of frost over extensive areas in a small drainage increased the runoff 3 to 4 times.

A COVER OF vegetation and snow greatly influences the structure of frozen soil and the penetration, persistence, and extent. A litter of pine needles can keep the soil from freezing hard—the intergranular spaces of the litter-covered soil are not filled so noticeably with ice as occurs in soil from which the litter is removed.

Concrete freezing has been observed most frequently in cultivated fields. Honeycomb and stalactite frost, which usually occur during shallow freezing, are found most frequently in meadows and pastures. In forested areas frost of the granular type is found oftenest. Honeycomb frost is next in frequency.

The type and composition of the forest cover, the condition of the stand, and the forest floor have a great bearing on the type and degree of soil freezing. Measurements of soil freezing during the winter of 1950–1951 in New York and New England show the general relationships between forest type and concrete soil freezing. Observations of soil frost were made in southern New York on plots covered with hardwoods, of pole and sawtimber size, and on other plots covered with comparable coniferous stands. Concrete soil freezing began to form under the coniferous stands 2 and 3 weeks before any was observed in the hardwood stands. The maximum depths reached in the coniferous stands were about 3 to 4 times greater than in the hardwood stands. All concrete frost had disappeared from the hardwood stands 3 to 4 weeks before it disappeared in the coniferous stands. During the time that concrete frost was present, about 25 percent of the hardwood-covered area contained frozen soil, but 50 to 75 percent of the area in the coniferous-covered area was concretely frozen.

Measurements of soil freezing were made that winter in two plantations of white pine in northern New York. One was 20 to 25 years old. The second was about 35 years old. Concrete frost started forming a few days earlier in the young plantation, was 2 or 3 inches deeper than in the older stand, and disappeared 3 or 4 days later than in the older stand. Both plantations had considerably less frost than nearby open land, but they had more frost than areas that had been continuously in forest.

In various parts of the country, especially in the Northeast, sizable areas of abandoned farmlands are found. Good stands of trees are becoming established on some of the abandoned fields, but little or no reproduction has occurred on other areas. Measurements of soil freezing were made in 1950–1951 in western Massachusetts in areas with and without good natural hardwood reproduction. The regions that had a good stand of natural reproduction started freezing concretely nearly a week later than those with no reproduction; the depth of penetration was 2 to 4 inches less on the area with natural reproduction and disappeared 10 days earlier in the spring.

The effect of disturbance of the forest floor by fire was determined by observations during the same winter on two areas in northern New York. One was covered with an undisturbed coniferous sawtimber stand. The second was covered with a coniferous sawtimber stand from which a large part of the litter and humus had been removed about a year earlier by a fire. Concrete freezing started in the burned area about 2 weeks before it started in the unburned area, was 3 or 4 times deeper, and lasted 2 or 3 weeks longer in the spring.

The effect of disturbing the forest floor by removing or destroying the litter and humus other than by fire and by compacting the soil was determined by the measurements on three stands of hardwood saw timber in northern New York. One stand was

comparatively undisturbed. The second had been selectively logged 2 years earlier. The third had been heavily grazed. The concrete freezing started about 2 weeks sooner in the grazed area than in either of the other two areas, reached a much greater depth, lasted about 3 weeks longer than in the logged area, and about 6 weeks longer than in the undisturbed area. There was more concrete freezing in the logged area than in the undisturbed area, but most of the concrete freezing occurred in the places where skidding of logs had removed the litter and humus and tended to compact the soil—the result there was a patchy pattern of concrete frost.

THE OBSERVATIONS made in the winter of 1950-1951 in the Northeast may be summarized thus:

Less concrete frost forms in hardwood stands than in coniferous stands of a comparable size.

The establishment of the coniferous plantations retards the formation of concrete freezing, as compared with open land conditions, but does not shorten the time when the frost leaves the ground in the spring. Coniferous plantations seem to retard the formation of concrete frost less than does the natural development of hardwood reproduction.

Establishment of hardwood tree reproduction on abandoned fields will reduce the amount of the concrete soil freezing.

A disturbance of the forest floor, by the destruction or removal of litter and humus and compaction of the surface mineral layers, greatly increases the amount of concrete freezing. The amount of concrete freezing is directly proportional to the degree of disturbance of the forest floor.

Concrete freezing of the soil in open lands develops sooner than in forested areas and is deeper and more widespread. Concrete frost disappears in the spring from open lands as soon as in the dense coniferous stands—sometimes sooner.

Well-stocked hardwood sawtimber stands, if ungrazed, have less concrete soil freezing than any other land use or condition.

MANY OBSERVATIONS on the structure of frost were made in New England during the winter of 1945-1946. In open areas the frost was either of a solid or concrete type of structure from the surface down to its full depth of penetration, or of a loose structure in the upper 3 or 4 inches, and solid at the greater depths. The concrete type usually occurred in cultivated fields. The loose type usually occurred in meadows where there was abundant humus. Only occasionally was a concrete type of structure found in a wooded area that had a good deal of organic matter. The most notable exceptions were spruce flats that had high water tables; there the soil was frozen rather solidly to depths of more than 12 inches.

Frost tends to form in a granular or honeycomb structure in soils containing considerable humus. The incorporation of organic matter into a mineral soil by natural processes may cause aggregation of the soil particles and thereby increase the noncapillary pores of the finer textured soils. The reduction of percolation rates is more marked in finer grained than in coarse-textured frozen soils. Since coarse-textured and aggregated soils generally contain larger and more noncapillary pores than fine-textured soils, it is possible that soil structure, as influenced by organic matter, is also a factor in the determination of frost structure.

Available data indicate that:

A concrete type of frost structure is formed in practically all soils which have been largely depleted of humus.

In the presence of humus, frost in the soil is usually of a porous structure.

A concrete type of frost structure is formed in heavily compacted soils, irrespective of the humus content.

A concrete type of frost structure frequently forms when frost penetrates below the humus layer. In lightly com-

pacted pastures and meadows this occurs usually at depths below 3 or 4 inches.

Depth of soil freezing is affected, in general, by most of the same factors that control the type of frost structure formed. This is to be expected, as the concrete type of frost is associated with deeper freezing, whereas the more porous types of frost are usually found if conditions favor shallow freezing.

Open lands tend to freeze more deeply than undisturbed forest lands. One major exception is the case of coniferous stands on poorly drained soils, which may freeze as deeply as open lands or more deeply. Hardwood stands consistently freeze to shallower depths than any other areas unless the litter and humus have been disturbed by fire, logging, or grazing.

A study in Connecticut disclosed that litter and duff of a mixed red pine and white pine plantation reduced frost penetration by 40 percent.

Another study carried on in the Northeast in 1939-1940 demonstrated the effect of removing the litter and humus. Paired plots were established among hardwoods and in a stand of white pine. On one of each pair of plots all the litter and duff were removed. The other plot was left undisturbed. In the hardwood plots without humus, frost was present almost continuously for the entire period of observation and reached a depth of nearly 3 inches. On the undisturbed plots, frost was observed on only 2 days, and then only a few tenths of an inch in depth. Frost penetration in the undisturbed plot of white pine was 3.5 inches deep by the end of the observation period; in the companion plot, where the humus had been removed, frost went 8 inches deep.

Snow, particularly light, new snow, has value as an insulator and tends to retard deep penetration of frost. Even when freezing was severe, 24 inches of snow has prevented frost penetration. At other times, in less severe weather, 12 to 18 inches of snow have prevented frost penetration. A number of obser-

vations have shown that even though frost penetration has started before the first snow, when snow depths have reached 18 to 24 inches further penetration has stopped. Hardwood forests in general develop about the most effective snow cover for retarding frost penetration. Wind movement in a hardwood forest is consistently low because of the retarding effect of the bare trunks and limbs; thus little drifting occurs, and the snow is distributed evenly over the soil surface. Hardwoods also intercept little snow as compared with conifers; therefore snow accumulation tends to be greater there than in coniferous stands. Bare fields, on the other hand, are frequently swept clean by winter winds, with the result that large areas are without a protective snow covering and are subject to deep penetration.

PERSISTENCE of concrete frost during rain or snowmelt periods, particularly in the spring, is important from a hydrologic standpoint. If such frost would always disappear before rain or snowmelt could produce surface runoff, it would have little significance.

Often soil freezing will start before the first snow accumulation and will continue until snow is deep enough to prevent further freezing of the soil. If the snow stays that deep or deeper, thawing will begin at the lower edge of the frozen zone of soil because an accumulation of heat rises toward the ground surface from warmer depths below. Soil frozen to a considerable depth can thaw under a snow cover of 30 or 40 inches. When the snow has disappeared, the frozen soil starts thawing from the top while continuing to thaw also at the bottom edge. Usually the last remnant of frost is found midway between the point of maximum penetration and the surface.

Frost seldom penetrates to uniform depths, even in places a few feet apart, because of the variability of the micro-physical environment. The lack of uniformity is especially significant during a period of snowmelt. When frost is

thawing, the shallower depths of frost disappear first.

Studies in New England showed that the extent of frost in forested areas declined before or during the snowmelt period, but frost remained in nearly all open areas during the entire period of snowmelt.

Another study in south central New York, which covered entire subwatersheds ranging from 7 to 1,335 acres, disclosed no frost in three out of four wooded watersheds. Frost was present in a fourth watershed in only 12 percent of the area. Thus frost may occur only in parts of a watershed while the rest of the basin may be free of frost. Cultivated watersheds showed frost penetration everywhere at the beginning of the snowmelt period; the extent dropped to about 50 percent of the area by the end of the melt period. About 65 percent of pastured watersheds had a maximum of frost penetration but had no frost by the end of the snowmelt period.

In conclusion: Considerable changes in the type and extent of soil freezing may be brought about by changes in the way land is used and by the condition of vegetative cover. They in turn cause changes in infiltration, percolation, and runoff and have a vital bearing on floods in winter and spring.

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